TABLE 32. POLLUTANT CONCENTRATIONS IN STORMWATER RUNOFF, OKLAHOMA CITY, OKLAHOMA, AND SANTA CLARA COUNTY, CALIFORNIA
mg/L

Oklahoma City, Oklahoma

Land classification	TSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	PO_4-P	OPO_4-P	Lead	Fecal coliforms[a]
Central city	202	32	289	4.2	4.7	1.7	1.7	0.78	24 000
Central city	355	33	125	2.3	3.5	2.1	2.1	0.44	130 000
Residential urban	88	30	101	2.3	4.0	0.66	0.70	0	14 000
Suburban	6	9	22	0.5	2.0	0.06	0.06	0	22 000
Rural	87	5	45	1.1	1.9	0.49	0.46	0	10 000
Total									
Mean	147	22	116	2.1	3.2	1.00	1.00	0.24	40 000
Range	3-639	1-34	0-392	0-0.5	0.4-15.8	0-3.69	0-3.69	0-2.23	8 000-160 000
No. of samples	40	40	40	40	40	39	40	12	20
Woodland	63	7	44	0.6	0.6	0.05	......	0	2 900

Santa Clara County

Land classification	TSS	VSS	BOD	COD	Nitrogen	PO_4-P	Lead
Residential	457	107	37	...	7.2	0.34	....
Residential	512	92	17	152	2.9	0.18	0.4
Commercial	120	53	23	255	9.4	0.29	0.98
Industrial	123	52	14	119	6.0	0.14	(5.0)[b]
Industrial	42	21	11	104	3.8	0.16	0.65
Mixed	341	78	24	......	5.9	0.24	....
Total							
Mean	284	70	20	147	5.8	0.23	0.75
Range	0-2 252	0-604	2-73	81-255	1.0-26 9	0.05-.90	0.35-1.45
No. of samples	78	77	64	5	73	66	8

a. Organisms/100 mL.

b. Includes industrial discharge--not used for mean.

Pullach, Germany--

The one non-American study cited was an extensive sampling effort in southern Germany where approximately 1200 samples were taken for 62 runoff events. The program covered a complete year in a 23 ha (57 acre) suburban basin that was described as having "the character of a small town" with residential areas and a town center. The flow weighted averages from the sampling program were shown in Table 21. The length of the program allowed the investigation of pollutant concentration variation with seasons. The climate of Pullach is similar to the northeast and midwest sections of the United States with 95 cm (37 in.) of rain, 108 cm (42 in.) of snow, and mean monthly temperatures ranging from -2°C to 17.5°C (28°F to 64°F). The variation for key pollutants is shown in Figure 14. The high winter loading of suspended solids is attributed to washoff of deicing grit and roadway material worn away by studded snow tires. The peak month was April when the accumulated winter solids would be removed by spring rains. The BOD concentrations did not follow any explainable pattern. The bacterial fluctuations appear to be based on climatic conditions with higher concentrations in the warm summer months that would allow for longer survival times.

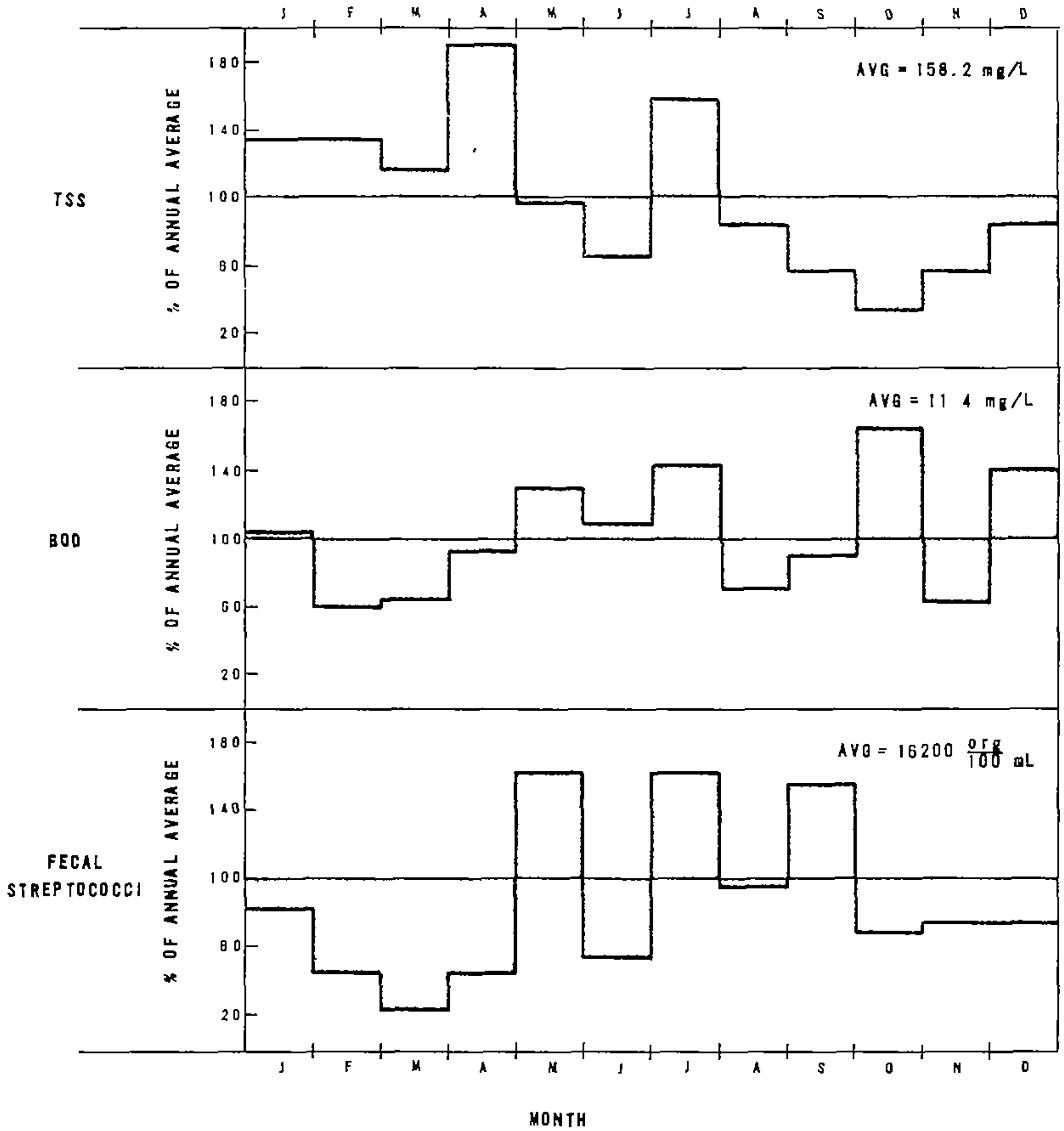

Figure 14. Variation of pollutant concentrations by month in Pullach, Germany [3].

Combined Sewer Overflows

In many cities, especially those with older sewer systems, the storm runoff and sanitary sewage flow in the same conduits and overflow as a mixture when the pipe capacity is exceeded during a storm. Sampling programs have been developed to characterize the quality of the overflows for the predesign of abatement programs. The pollutant values are a combination of runoff pollutant concentrations, as described in the previous section, and sanitary sewage pollutant concentrations. Site specific concentrations that result from this mixture are dependent on the quality of the two base flows and the proportional mix. A summary of data from several studies is shown in Table 33 and highlights of each study are given in the following paragraphs.

TABLE 33. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS

	Average pollutant concentration, mg/L									
	TSS	VSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	PO_4-P	OPO_4-P	Lead	Fecal coliforms[a]
Des Moines, Iowa [11]	413	117	64	...	...	4 3	1.86	1.31	..	....
Milwaukee, Wisconsin [15]	321	109	59	264	4.9	6.3	1 23	0.86	..	.
New York City, New York										
Newtown Creek [16]	306	182	222	481	...	..	.....	....	0 60	..
Spring Creek [17]	347	..	111	358	...	16.6	4 5[b]	.	...	....
Poissy, France [18][c]	751	387	279	1005	...	43	17[b]	....	...	.. .
Racine, Wisconsin [19]	551	154	158	...	...	....	2.78	0.92	....	201
Rochester, New York [20]	273	...	65	...	2.6	. .	.....	0.88	0 14	1140
Average (not weighted)	370	140	115	367	3.8	9.1	1.95	1.00	0.37	670
Range	273-551	109-182	59-222	264-481	2.6-4.9	4.3-16.6	1.23-2.78	0.86-1.31	0.14-0.60	201-1140

a. 1000 organisms/100 mL.

b. Total P (not included in average).

c Not included in average because of high strength of municipal sewage when compared to the United States.

Des Moines, Iowa--

The pollutant concentrations shown in Table 34 indicate that the overflows are less concentrated than sanitary sewage for all pollutants except solids [11]. Although the areas sampled had varying percentages of combined and separate sewers, the pollutant concentrations did not appear to be related to the variation.

TABLE 34. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, DES MOINES, IOWA [11]

Site	Mean value for pollutants, mg/L							Comments
	TSS	VSS	BOD	NH_3-N	Total nitrogen	PO_4-P	OPO_4-P	
0-2	495	95	44	1.21	2.12	0.72	0.41	6% combined sewers
0-3	144	77	69	4.53	4.87	3.83	2.70	6% combined sewers
0-6	592	181	95	9.42	10.19	3.23	3.02	25% combined sewers
0-7	195	62	50	1.84	3.0	2.32	0.99	33% combined sewers
0-8	410	142	68	3.22	4.32	2.27	1.66	69% combined sewers
0-8a	303	101	77	4.94	5.54	...	1.98	81% combined sewers
CSO summary								
Mean, mg/L	413	117	64	3.36	4.32	1.86	1.31	
Range, mg/L	10-1 549	2-582	9-220	0-27.4	0.2-27.6	0.27-6.6	0.01-84	
No. of samples	64	64	69	56	56	39	47	
Sanitary sewage	230	170	195	24.3	25.1	5.7	3.6	

Milwaukee, Wisconsin--

The data presented in Table 35 summarize the influent flow quality to a screening pilot plant operated at the Hawley Road combined sewer overflow; data from four test periods and a breakdown between the first-flush and the remainder of the storm for a fifth test period are shown [15]. It is generally assumed that quantities of sanitary sewage settle out in the large combined sewers during periods of low flow and, as a storm event begins, the material is resuspended. This means that the first portion of a storm will carry exceptionally high pollutant concentrations. The data confirm that the initial part of an overflow at Hawley Road has pollutant concentrations that are much higher than later parts of a storm. The concentration of the first-flush appears to be related to the number of dry days preceding the storm event. Solids accumulate over the dry period and longer intervals provide a larger mass of pollutants for resuspension. The relationship between dry intervals and first-flush concentrations is shown in Figure 15. Although a simple equation would not provide a good correlation for the points, it is apparent that the dry period influences pollutant concentration.

TABLE 35. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, MILWAUKEE, WISCONSIN (HAWLEY ROAD) [15]

	Pollutant concentrations, mg/L							
Sampling period	TSS	VSS	BOD	COD	Kjedahl nitrogen	Total nitrogen	PO_4P	OPO_4-P
Preliminary data								
1967-1968	400	113	49	336	....	....	.....	.....
1971	435	146	64	209	....	6.3	.....	0.86
1973	129	52	42	...	4.9	....	0.99	.....
1974	162	87	74	...	....	....	1.47	.....
Summary								
Mean	321	109	59	264	4.9	6.3	1.23	
Range	32-2 158	12-720	4-318	26-1 410	1.9-14.3	1.0-27.9	0.25-4.04	0.06-0.93
No. of samples[a]	55	42	49	37	10	21	20	21
First flush								
1969-1970	522	308	186	581	....	17.6	2.7	......
Remainder of storm								
1969-1970	166	90	49	161	....	5.5	.....	......

a. Samples reported as averaged for overflow events.

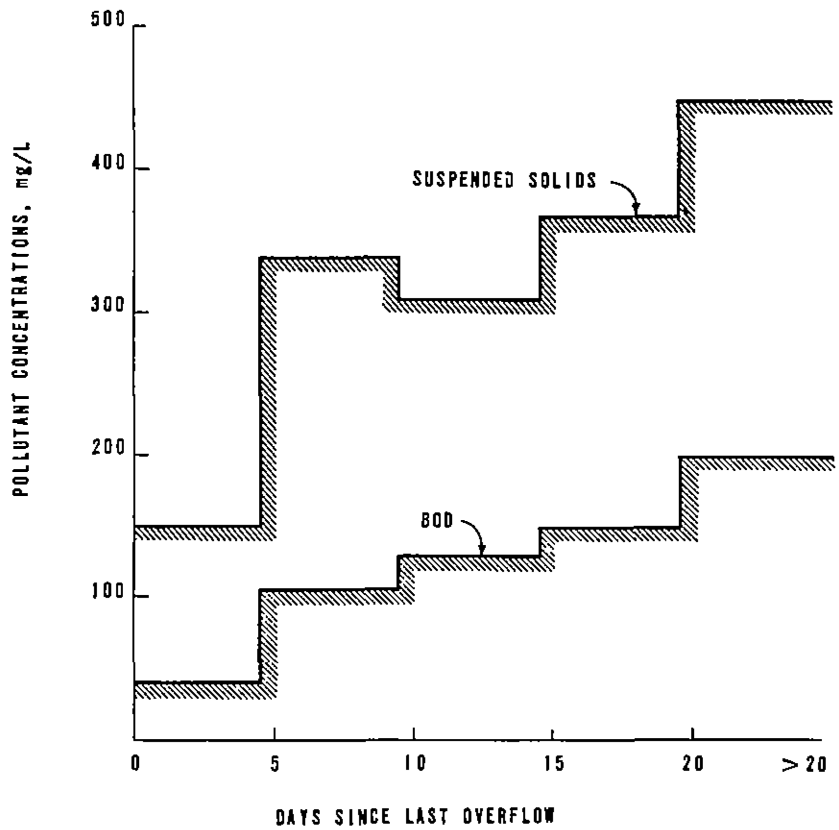

Figure 15. Average pollutant concentration versus preceding dry-weather period, Milwaukee, Wisconsin [15].

In a second study at Milwaukee's Humboldt Avenue Project [21] the first-flush phenomenon was also noted. Values for suspended solids and BOD during progressive overflow time intervals are shown in Figure 16. The data shown consist of average concentrations for samples from 97 storm events.

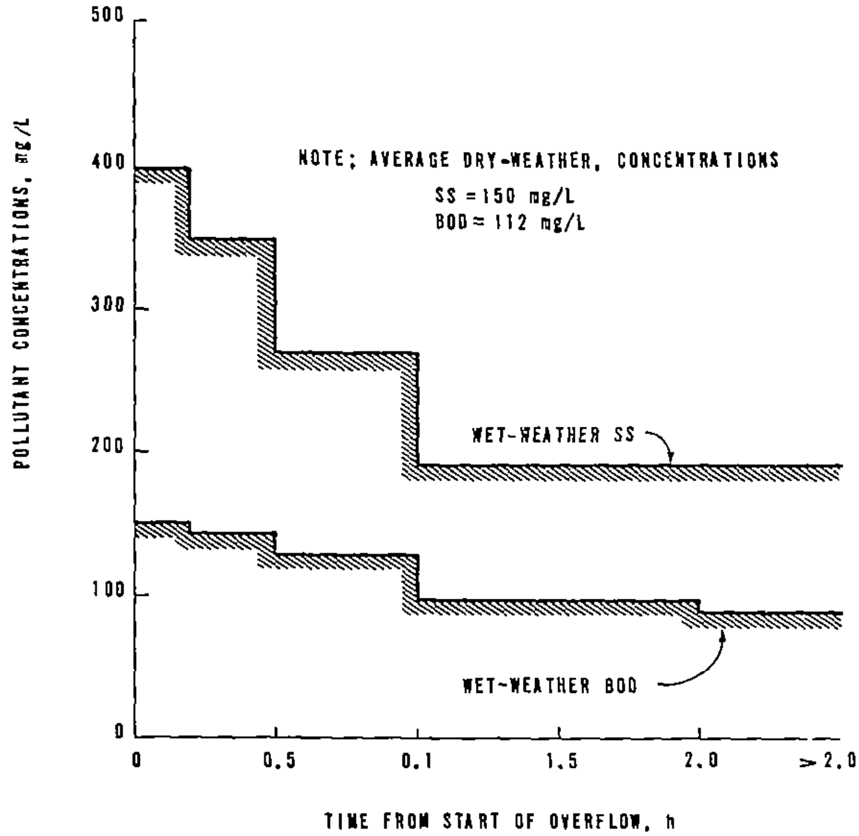

Figure 16. Overflow quality versus time at Milwaukee, Wisconsin [21].

New York City--

Combined sewer overflow sample data are available for two sites in New York City--the Newtown Creek and Spring Creek Water Pollution Control Facilities. At Newtown Creek an ultra high rate filtration pilot study was performed in 1976-1977 to test the feasibility of treating combined sewer overflows. The data in Table 36 are for composite samples from the pilot plant influent during six storms.

The second set of data from New York City is the result of a study of the ecosystem and sources of pollution for Jamaica Bay. The objective of the project was to evaluate an ongoing combined sewer overflow control program by developing estimates of pollutant input to the bay and modeling receiving water quality to determine the impacts of alternative control measures. Characerization of combined sewer overflows was accomplished by sampling five basins during a period from March 1969 until January 1971. The data are summarized by drainage basin in Table 37. Generally, the solids concentrations are much higher than sanitary sewage while the organics are similar to sewage.

TABLE 36. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, NEW YORK CITY, NEW YORK - NEWTOWN CREEK [16]

	Pollutant concentrations, mg/L										
	TSS	VSS	BOD	COD	Pb	Cd	Cr	Cu	Hg	Ni	Zn
Storm 0	608	...	315	562	1.28	.035	6.0	0.6	.0022	0 80	1.00
Storm 1-1	232	180	188	498	0.33	.035	0.55	0.32	.0008	0.28	0.57
Storm 1-2	132	120	130	344	0.19	.0087	0.35	0.26	.0002	0.22	0.46
Storm 2	248	184	240	483	0.6	.018	0.90	0.44	.0002	0.60	0.60
Storm 3	380	252	235	551	....	......	....	....	......	....	....
Storm 4	236	176	222	449	....	......	....	....	......	....	....
Summary											
Mean	306	182	222	481	0.60	.024	1.95	0.41	.0009	0.27	0.63
Range	132-608	120-252	130-315	344-562	0.19-1.28	.0087-0.35	.35-6.0	.26-0.6	.0002-.0022	.08-.50	.46-1.00
No. of samples[a]	6	5	6	6	4	4	4	4	4	4	4

a. Composite samples taken over storm duration.

TABLE 37. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, NEW YORK CITY, NEW YORK (SPRING CREEK) [17]

	Pollutant concentrations, mg/L					
Sites	TSS	BOD	COD	Total nitrogen	Total phosphorus	Soluble phosphorus
Paerdegat	81	79	...	15.9	11.7	0.9
Hendrix	255	127	383	17.3	5.3	3.9
Spring Creek West	341	95	259	20.6	3.8	2.8
Spring Creek East	556	142	424	18.2	4.4	3.3
Thurston	223	89	382	10.5	2.4	1.8
Summary						
Mean	347	111	358	16.6	4.5	2.8
Range[a]	51-1 050	7-340	54-600	1.9-38	....	0.17-10
No. of storms	41	31	10	25	29	29
Sanitary sewage	145	119	391	44	9	6

a. Data reported as flow weighted mean for a storm.

Poissy, France--

Eight storm events were sampled during a September-to-July period in Poissy, France. The samples were part of a characterization study to develop annual loads from storm events in the Paris region. The results are listed in

Table 38 and compared to the sanitary sewage concentrations for the same system. It is apparent that the sewage is more concentrated than an average American sewage.

TABLE 38. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, POISSY, FRANCE [18]

	Pollutant concentrations, mg/L					
	TSS	VSS	BOD	COD	Total nitrogen	Total phosphorus
Storm 1	417	314	147	783	....	....
Storm 3	420	217	130	558	18.5	6.3
Storm 4	307	176	80	267	13.1	3.5
Storm 6	275	161	298	1 463	61	13
Storm 7	1 545	636	424	1 742	65	33
Storm 8	845	321	250	464	33	25
Storm 9	976	453	277	861	38	9.4
Storm 10	1 223	821	628	1 903	74	27
CSO totals						
Mean	751	387	279	1 005	43	17
Range	275-1 223	161-821	80-628	267-1 903	13.1-74	3.5-27
No. of samples	8	8	8	8	7	7
Sanitary sewage	280	230	330	960	73	26

From these sampling efforts, annual loads of pollutants were estimated for the basin. Three primary pollutants were estimated with suspended solids as a function of runoff flow rate, COD as a function of runoff volume, and BOD as a function of volume or runoff rate. The mass loadings were estimated for each storm and summed over a year to estimate annual loads.

Racine, Wisconsin--

The Racine project was an evaluation of three full-scale demonstration systems for the treatment of combined sewer overflows. Three sets of raw overflow data were available from the preliminary investigation prior to setup and two additional sets were compiled from the demonstration runs. The concentrations are tabulated in Table 39.

There are some large differences in pollutant concentrations for different sites and time periods. The temporal variations were attributed to sampling methods and changes in the sewer system; the variation between sites was attributed to the fact that sewers tributary to Site 1 flow near capacity and will prevent deposition during dry weather, while sewers tributary to Site 2 flow well below capacity. The dry-weather deposition in the sewers will be exhibited as a "first flush" of heavily concentrated overflow. During the 1971 preliminary phase, individual samples were taken during the 10 events monitored at Site 2. Average values were computed for time periods from the start of overflow and plotted in Figure 17. The graph shows the tendency for high initial concentrations.

TABLE 39. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, RACINE, WISCONSIN [19]

	Pollutant concentrations, mg/L						
	TSS	VSS	BOD	TOC	PO_4-P	OPO_4-P	Fecal coliform[a]
Site 1 - overflow 1, 1971	298	...	79	98	.....	0.64	10 300
Site 1 - overflow 3, 1971	669	...	212	194	.....	2.07	21 900
Site 2 - overflows 7-8, 1971	669	...	212	238	.....	0.75	10 100
Site 1, 1974	266	134	93	95	3.13	.....	609 000
Site 2, 1974	661	178	110	122	2.38	.....	416 000
Summary[b]							
Mean	551	154	158	172	2.78	0.92	201 000
Range	38-2 070	26-475	27-510	24-459	1.0-5.62	0-3.17	540-4 400 000
No. of storms	108	41	108	106	41	69	107

a. Organisms/100 mL.

b. Based on storm event composites.

Rochester, New York--

The data base for Rochester was gathered as part of a study to optimize storage treatment capacities in the combined sewer system. A large number of samples were taken at 12 overflow sites during an 18 month period. The results are shown in Table 40 by overflow site along with an indication of principal land uses for areas that are tributary to each overflow. Concentrations are not readily correlated to land use. The "first flush" phenomenon occurred in Rochester as it did in Milwaukee and Racine. Average pollutant concentrations for storm intervals are graphed in Figure 18 and show a significantly decreasing value for increasing time.

Summary of Discharge Data

The average pollutant concentrations for urban runoff and combined sewer overflows are compared to background pollution and sanitary sewage in Table 41. The background data are the reported range of quality constituents from the USGS National Hydrologic Benchmark Network that was established to obtain a natural background. The ranges are for average values across the country. The sanitary sewage values represent common design values used to characterize a medium strength municipal sewage.

The ten common pollutants listed in Table 41 have been extensively surveyed in stormwater studies as indications of pollution from solids, organics,

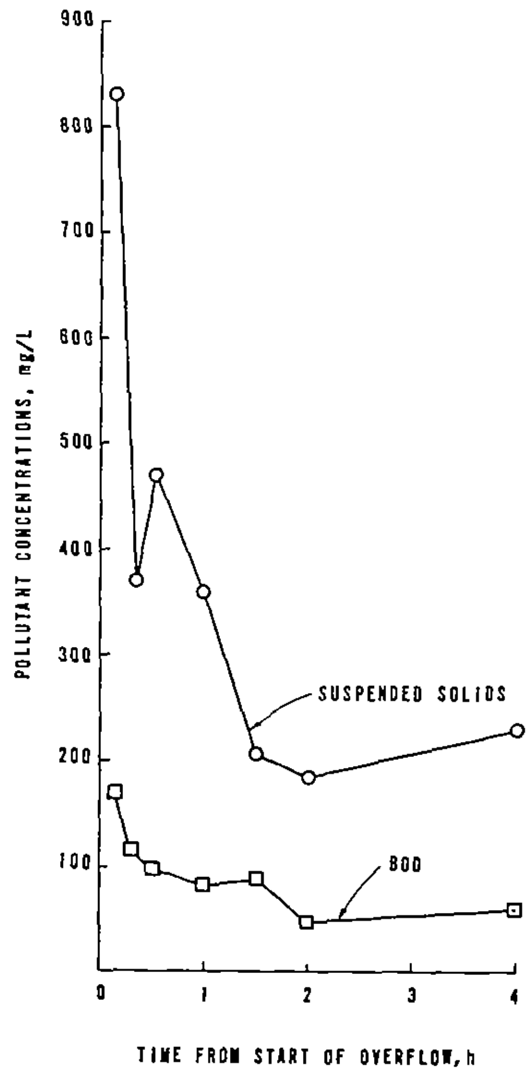

Figure 17. Overflow quality versus time at Racine, Wisconsin [19].

nutrients, toxic metals, and pathogens. In most cases these parameters will be sufficient to characterize runoff problems and impacts. However, in recent years there has been an increasing awareness of potential danger to receiving waters from low concentrations of metals, pesticides, and microorganisms. Typical values obtained for parameters in each category are shown in Tables 42, 43, and 44. The values were obtained for a variety of reasons under different conditions and are presented as representative of ranges that may be expected

Urban rainfall-runoff-quality data have been assembled on magnetic tape by the University of Florida [22]. So far eight sites are incorporated in the project including Broward County, Florida; San Francisco, California; Racine, Wisconsin; Lincoln, Nebraska; Windsor, Ontario; Durham, North Carolina;

TABLE 40. POLLUTANT CONCENTRATIONS IN COMBINED SEWER OVERFLOWS, ROCHESTER, NEW YORK [20]

Site	Mean pollutant concentration, mg/L						Principal land uses
	TSS	BOD	TOC	Kjeldahl nitrogen	TIP[a]	Fecal coliform[b]	
7	289	...	53	5.5	0.69	1.12	Residential
8	203	75	44	4.3	0.48	0.58	Commercial-Residential
9	219	129	70	11.0	1.00	0.53	Residential-Industrial
16	368	99	79	2.8	0.32	0.85	Residential-Commercial
17	142	34	30	2.2	2.56	1.10	Residential
18	192	66	38	3.7	0.77	1.11	Residential
21	124	71	50	7.5	0.71	1.69	Residential
22	512	...	223	7.0	1.97	1.90	Residential
25	207	52	35	3.8	0.42	0.81	Commercial-Residential
26	395	23	28	0.9	0.14	0.12	Commercial-Residential
28	244	63	48	2.4	0.33	1.18	Residential
31	173	79	49	2.5	1.18	1.22	Residential-Commercial-Industrial
Summary							
Mean	273	65	72	2.6	0.88	1.14	
Range	4-29 590	0-610	0-1 420	0-94	0-77.6	0-70	
No. of samples	1 976	1 184	2 358	2 383	2 385	1 709	

a. Total inorganic phosphate as P.

b. Million organisms/100 mL.

Lancaster, Pennsylvania; and Seattle, Washington. The computerized data will be available for characterization studies and the calibration and verification of runoff models. There are many additional past and current studies that can be added to the project to expand the data base.

Normalization of Data

The discharge data in the preceding subsection have been developed as concentrations for the two basic categories of storm discharges--urban stormwater runoff and combined sewer overflows. It is evident from the comparison in Table 41 that normalization by discharge system type is a primary consideration. The values in this table represent a random cross-section of sampling experience for the two types of systems and as such are a valid starting point for the analysis of urban stormwater discharges. The brief descriptions of the studies behind the data indicate that the samples represent mixed urban areas for extended time periods. The values may not be representative for small homogeneous drainage basins or individual storm events.

In most cases, an investigator is interested in the mass of pollutants that are tributary to the receiving water. The concentrations developed must be

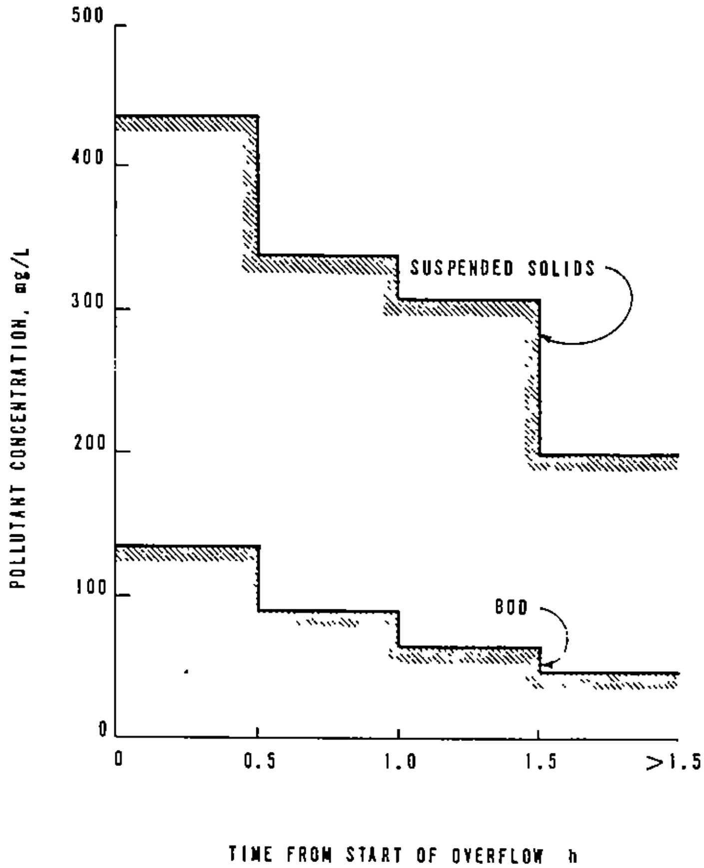

Figure 18. Overflow quality versus time at Rochester, New York [20].

TABLE 41. COMPARISON OF TYPICAL VALUES FOR STORMWATER DISCHARGES[a]

	TSS	VSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	Total PO_4-P	OPO_4-P	Lead	Fecal coliforms
Background levels [9]	5-100	...	0.5-3	20	.....	0.05-0.5[b]	0.01-0.2[c]	...	<0.1	....
Stormwater runoff	415	90	20	115	1.4	3.10	0.6	0.4	0.35	13 500
Combined sewer overflow	370	140	115	367	3.8	9.10	1.9	1.0	0.37	670 000
Sanitary sewage [23]	200	150	200	500	40	40	10	7	....	....

a. All values mg/L except fecal coliforms which are organisms/100 mL.

b. NO_3 as N.

c. Total phosphorus as P.

TABLE 42. METAL CONCENTRATIONS IN STORMWATER RUNOFF AND OVERFLOWS

Site	Pollutant concentrations, mg/L								
	Cadmium	Chromium	Copper	Nickel	Zinc	Iron	Lead	Manganese	Magnesium
New York City, New York [24]	0.025	0.16	0.46	0.15	1.6	.....	....	....	..
Durham, North Carolina [12]	......	0.23	0.15	0.15	0.36	12.	0.46	0.67	10
Rochester, New York (2 sites) [20]	0.0021	0.0065	0.086	0.013	0.24	1.66	0.14	....	..
Drinking Water Standards [6]	0.01	0.05	1.0	.....	5.0	0.3	0.05	0.05	..

a. Maximum permissable concentrations.

TABLE 43. PESTICIDE AND HERBICIDE CONCENTRATIONS IN STORMWATER RUNOFF AND OVERFLOWS
Parts per Trillion

Pesticide and herbicide	Racine, Wisconsin [19]						Hayward California [25] 1971-1972		Drinking water standards [26][a]
	1971	1973		1974					
	Site 11	Site 11A	Site 11	Site 1	Site 11	Site 11A	Average	Maximum	
Lindane	<1	90	130	<1	<1	<1	31	150	5 000
Heptachlor	<1	<10	<10	<1	<1	<1	0	0	100
Aldrin	14	<10	<10	<1	<1	<1	4	70	1 000
Heptachlor epoxide	16	<10	<10	32	23	<1	0	0	100
Methozchlor	58	<15	<15	<1	<1	<1	...	.....	10^6
Dieldrin	<1	120	<10	<1	14	<1	90	190	1 000
Endrin	<1	260	100	<1	<1	<1	0	0	500
Methyl parathion	..	...	..	..	..	..	0	0	......
Parathion	..	..	.	..	..	..	0	0	......
DDT	..	...	...	61	89	5	130	630	50 000
DDD	..	...	...	26	34	5	6	80	......
DDE	..	...	...	<1	<1	<1	16	100	......
Chlordane	..	...	...	..	.	..	560	2 400	3 000
Diazinon	..	...	...	..	..	..	195	260	......
Malathion	..	...	..	.	..	..	128	540	.. ...
Silvex	..	...	...	..	..	..	81	560	30 000
2,4-D	..	...	...	..	..	..	570	6 400	20 000
2,4,5-T	..	..	...	..	..	..	63	200	2 000

a. Maximum permissible concentrations.

TABLE 44. MICROORGANISMS IN STORMWATER RUNOFF AND OVERFLOWS

	Organisms/100 mL							
	Total coliforms	Fecal coliforms	Fecal streptococci	Enterococci	*Staph. aureus*	*P. aeruginosa*	*Salmonella* sp	Enterovirus, PFU/10 L
Baltimore, Maryland [26]								
Stormwater	120 000	24 000	170 000	50 000	38	1 100	0.13	34
Combined sewer overflow	590 000	230 000	260 000	72 000	38	5 900	0.59	92
Houston, Texas [27]								
The Woodlands, a developing community								
Upstream	258 000	1 300	650	...	450	85	<38	..
Downstream	403 000	1 800	2 020	.. ..	2 240	260	<62	..
Westberry Square, a residential area	30 100 000	22 000	13 100	...	8 120	7 560	<33	.

paired with volumes of runoff or overflow to get a loading. Consequently, the concentrations used should have been developed as flow weighted values so that the combination of concentration and flow gives an accurate loading. Most of the concentrations developed in the literature are simple averages of random samples and give undue weight to low volume-high concentration flow. A flow weighted concentration can also be expressed in different dimensional terms. Mass of pollutant per unit area of basin per unit depth of runoff (kg/ha per cm) has been suggested as a replacement for mg/L and parts per million [28].

Normalization can be extended to other factors that influence pollutant concentrations. The three most common categories are land use classes, runoff volume or rate, and time from start of event.

Land Use--

Normalization of data as a function of land use is important to areawide characterization studies because of the need to rank the pollutant potential of different areas and the need to project pollution loadings for future growth options. Ranking allows the concentration of available money on problem areas to maximize the decrease in pollution per dollar spent and also establishes a priority list for phased development of control programs. Projection of future pollution potential by land use allows planners to direct potentially damaging growth away from environmentally sensitive areas.

The effect of land use on solids deposition is shown in Section 4. The data for that evaluation were obtained by sweeping street surfaces in areas that could easily be identified as residential, commercial, or industrial. Studies of stormwater discharges and overflows have not been able to concentrate on small areas with easily definable land use characteristics. Most samples have been taken from mixed basins with at least two classifications and some open space.

An analysis of quality based on land use was developed in an EPA report [29]. The basis of the analysis was a tabulation of BOD concentration in storm discharges for residential areas from several cities. The remaining parameters and land use classifications were developed as ratios of this discharged BOD, using data acquired from the street surface sampling projects mentioned previously. The methodology was originally developed to project annual loads. The factors were converted to concentrations in another EPA report by assuming runoff coefficients (runoff/precipitation) for each land use area [30]. The residential data must also be modified by a population factor $p_1(PD_d)$ which is a function of population density.

$$p_1(PD_d) = 0.142 + 0.134\,(PD_d)^{0.54} \qquad \text{(SI units)} \qquad (5\text{-}3a)$$

$$p_1(PD_d) = 0.142 + 0.218\,(PD_d)^{0.54} \qquad \text{(U.S. customary units)} \qquad (5\text{-}3b)$$

where PD_d = developed area population density, people/ha (people/acre)

The factor is equal to one at a density of 31 people per hectare. The concentrations and runoff coefficients are presented as a function of land use in Table 45.

TABLE 45. POLLUTANT CONCENTRATIONS AS A FUNCTION OF LAND USE

	Pollutant concentrations, mg/L					
	TSS	VSS	BOD	PO_4-P	Total nitrogen	Runoff coefficient
Urban runoff						
Residential[a]	240	140	12	0.16	1.9	0.3
Commercial	140	90	20	0.16	1.9	0.7
Industrial	215	105	9	0.17	2.0	0.6
Other developed areas	17	16	1	0.02	0.4	0.1
Combined sewer overflows						
Residential	990	570	50	0.67	8.0	0.3
Commercial	580	360	85	0.64	7.7	0.7
Industrial	880	430	35	0.66	8.4	0.6
Other developed areas	70	70	3	0.08	1.6	0.1

a. Modify residential values by factor $p_1(PD_d) = 0.142 + 0.134\,(PD_d)^{0.54}$. (PD_d) = people/ha.

Because of the methodology used to develop this table, the values for combined sewage overflows are very questionable. The BOD values in combined sewage are principally attributed to the sanitary sewage and the ratios of BOD to other pollutants are much different in sanitary sewage as compared to street solids. The solids values estimated for combined sewage are high and the nutrient values are low. Satisfactory values for combined sewage have not yet been developed. Data could be developed at a specific site by combining the urban runoff concentrations in Table 45 with local estimates of the concentrations found in domestic or industrial sewage. The result would have to be volume weighted for the amounts of sewage and runoff expected at the overflow.

Precipitation and Runoff Characteristics--

The main goal of normalization of quality data as a function of precipitation or runoff is to make the loadings correlate to shorter time periods and storm events. Precipitation data are generally available in sufficient historical quantity to permit the estimation of probability of occurrence of rainfall volume, duration, intensity, and intervals. Several methodologies are also available for estimating runoff characteristics based on precipitation. All that is required to estimate pollutant loadings is to correlate runoff pollution concentrations to the runoff characteristics.

The work at Durham, North Carolina, was discussed previously and the equations developed there were presented in Table 27 [12]. The concentration of pollutants was developed as a function of runoff rate and time from the start of the storm in the form:

$$\text{concentration} = A(\text{rate of runoff})^x\ (\text{time})^y \qquad (5\text{-}4)$$

This equation will predict the pollutant concentrations at any time during a runoff event and can be integrated to get mass loading for an event. Samples from Durham indicated a very high solids content in the runoff and this probably means erosion problems in the natural drainage channels. Rate of runoff may not be an important parameter for areas with buried storm sewers or lined channels.

Regression analysis of pollutant concentrations as functions of precipitation was also attempted at Rochester, New York, and Tulsa, Oklahoma. The equations are presented in Table 46. Rochester has combined sewers and Tulsa has separate storm channels.

The relation between runoff characteristics and pollutant concentrations were shown in graphs developed for Des Moines, Iowa [11] and reproduced as Figure 19. The plots show the mass of pollutant from a unit area as a function of runoff. The values were based on composite samples for storm events and are valid only for complete events. In these graphs a straight linear curve would indicate a constant value for concentration regardless of the runoff volume. Most of the curves are slightly concave indicating a small decrease in composite concentration as the total volume of runoff increases.

This same relation was developed by regression analysis for Creteil, France, during a study of the effects of stormwater on Creteil's Lake [31]. The equations relate BOD and suspended solids mass loading to the volume of runoff per event. The original equations were:

$$\log (SS) = 1.298 \log (V) - 1.208 \qquad \text{(SI units)} \qquad (5\text{-}5a)$$

$$\log (SS) = 1.298 \log (V) - 2.85 \qquad \text{(U.S. customary units)} \qquad (5\text{-}5b)$$

$$\log (BOD_w) = 0.545 \log (\frac{V}{114}) + \log T \quad \text{(SI units)} \tag{5-6a}$$

$$\log (BOD_w) = 0.545 \log (V) + \log T - 1.62 \quad \text{(U.S. customary units)} \tag{5-6b}$$

$$\log (BOD_e) = 0.82 \log (\frac{V}{114}) + 0.398 \quad \text{(SI units)} \tag{5-7a}$$

$$\log (BOD_e) = 0.82 \log (V) - 2.215 \quad \text{(U.S. customary units)} \tag{5-7b}$$

where SS = mass loading, kg (lb)
BOD_w = mass loading due to washoff, kg (lb)
BOD_e = mass loading due to erosion, kg (lb)
V = runoff volume, m^3 (ft^3)
T = time since last rain, d

The equations can be factored for the 45.4 hectare basin and reduced to the forms:

$$SS = 76.2\ R^{1.298} \quad \text{(SI units)} \tag{5-8a}$$

$$SS = 228\ R^{1.298} \quad \text{(U.S. customary units)} \tag{5-8b}$$

$$BOD = 1.13\ R^{0.82} + T \times 7.48\ R^{0.545} \quad \text{(SI units)} \tag{5-9a}$$

$$BOD = 2.16\ R^{0.82} + T \times 1.48\ R^{0.545} \quad \text{(U.S. customary units)} \tag{5-9b}$$

where SS and BOD = mass loadings, kg/ha (lb/acre)
R = runoff, cm (in.)
T = time since last rain, d

A comparison of the Des Moines and Creteil data is made in Table 47. The higher values at Creteil may be due to the much higher population density of 220 people/ha (89 people/acre) as compared to approximately 25 people/ha (10 people/acre) in Des Moines.

Time--

Perhaps the most significant quality normalization criterion other than the type of system is related to the time of sampling with respect to the start of the event and the interval between events. Whether the primary cause is first flush or the declining availability of source contaminants, overflow or runoff quality tends to improve in the latter stages of a storm and in the latter storms of a storm series. Normalized comparisons of data from several cities with respect to time are summarized in Table 48. This quality-time relationship is particularly significant in optimizing storage-treatment operations where bypasses or multilevel treatment must be considered.

Summary--

Much more work is needed to develop valid normalization techniques that will simplify the analysis of stormwater problems. The present detailed techniques have not been calibrated at enough sites to test their applicability.

TABLE 46. POLLUTANT CONCENTRATIONS AS A FUNCTION OF PRECIPITATION CHARACTERISTICS

Equation	Correlation
Rochester [20]	
$COD = 50.17\ X_1^{0.0705}\ X_2^{0.0761}\ X_3^{-0.407}$	0.257
$TSS = 159.62\ X_1^{0.220}\ X_2^{-0.345}\ X_3^{-0.329}$	0.181
where COD and TSS are in mg/L	
X_1 = days since last rain	
X_2 = duration of rainfall, h	
X_3 = average intensity of rainfall, in./h	
Tulsa [14]	
$\ln(BOD) = 2.7531 + 0.0086(Z_1) - 0.6484(Z_2) - 0.3674(Z_5)$	0.274
$\ln(COD) = 4.5757 - 0.0246(Z_1) - 0.2001(Z_2) - 0.0900(Z_3)$	0.215
$\ln(TSS) = 5.7304 - 0.0144(Z_1) + 0.0572(Z_2) + 0.3004(Z_3)$	0.103
where BOD, COD, TSS are in mg/L	
Z_1 = time since start, h	
Z_2 = antecedent amount, in.	
Z_3 = antecedent average intensity, in./h	
Z_5 = amount of antecedent event, in.	

in./h x 2.54 = cm/h

TABLE 47. COMPARISON OF POLLUTANT LOADING ASSUMPTIONS AT DES MOINES, IOWA, AND CRETEIL, FRANCE

	Runoff, in.	Pollutant, lb/acre	
		Des Moines	Creteil
BOD[a]	0.1	0.75	2.4
	0.2	1.25	3.7
	0.3	1.80	4.6
SS	0.1	8	11
	0.2	19	28
	0.3	25	48

a. Assume T = 5 days

in. x 2.54 = cm
lb/acre x 1.121 = kg/ha

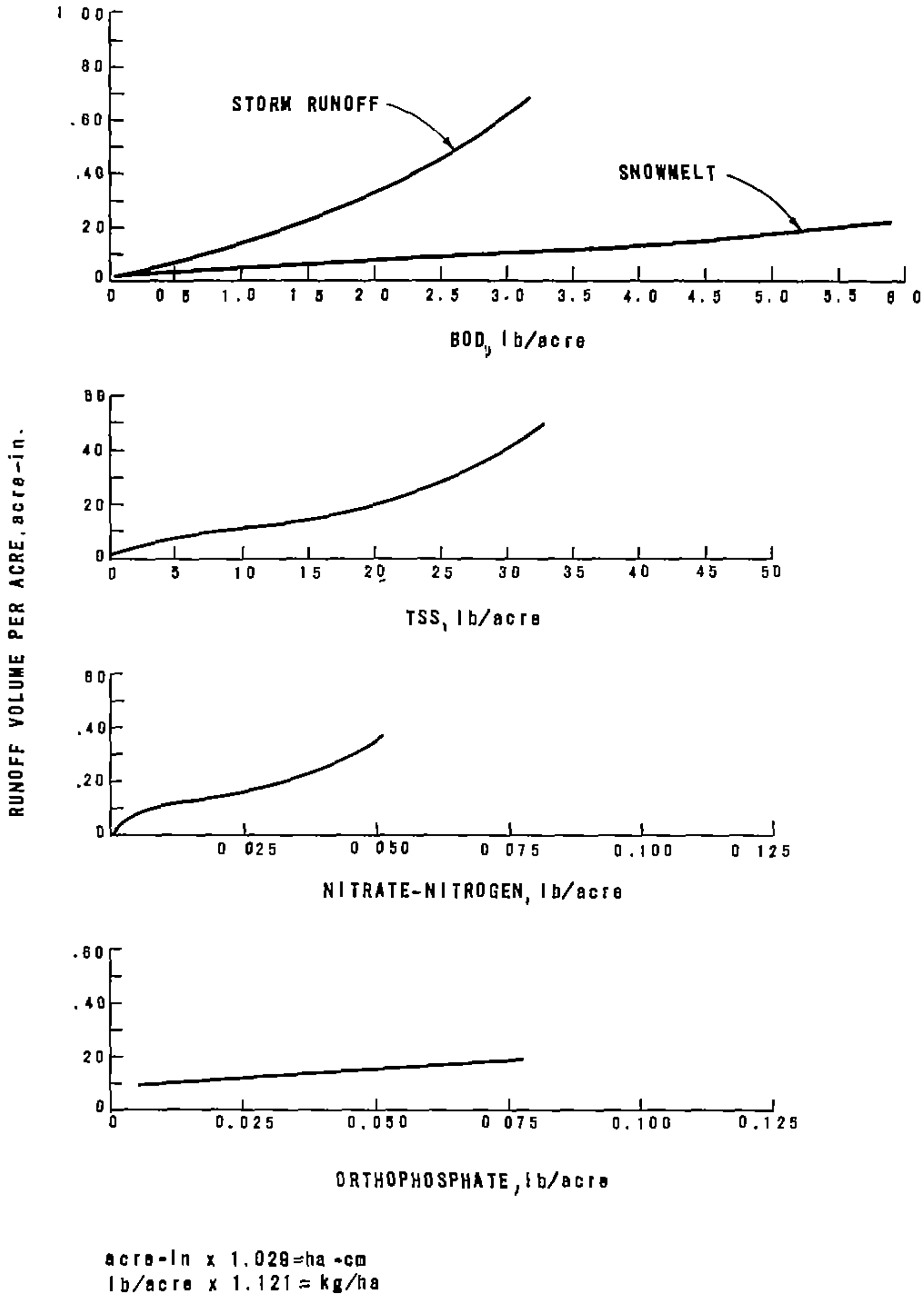

Figure 19. Runoff volume versus pollutants in Des Moines [11].

TABLE 48. TIME WEIGHTED NORMALIZATION OF BOD AND SUSPENDED SOLIDS

	Suspended solids				BOD			
	0-0.5 h	0.5-1 h	1-2 h	>2 h	0-0.5 h	0.5-1 h	1-2 h	>2 h
Combined sewer overflows								
District of Columbia [32, 33, 34]	1.0	1.07	0.91	0.88	1.0	0.73	0.47	0.30
Milwaukee, Wisconsin [21]	1.0	0.78	0.55	0.55	1.0	0.90	0.61	0.38
Racine, Wisconsin [19]	1.0	0.78	0.47	0.34	1.0	0.67	0.60	0.38
Rochester, New York [20]	1.0	0.78	0.67	0.44	1.0	0.66	0.43	0.34
San Francisco, California [22]	1.0	0.77	0.80	0.44	1.0	0.56	0.41	0.27
Storm sewer outfalls								
District of Columbia [32, 33, 34]	1.0	0 59	0.48	0.12	1.0	0.93	1.23	0.46
Racine, Wisconsin [19]	1.0	0.60	0.26	1.43[a]	1.0	0.69	0.66	1.82[a]
Durham, North Carolina [12]	1.0	0.92	0.73	0.57	1.0	0.36	0.39	0.20
San Francisco, California [22]	1.0	0.31	0.37	0.15	1.0	0.30	0.14	0.09
Tulsa, Oklahoma [14]	1.0	0.55	0.33	0.93	1.0	0.72	0.64	0.60

Note: Values indicate relative pollutant concentrations as fractions of the concentration for the initial time interval.

a. Values based on only one sample.

RESIDUALS

The treatment and disposal of sludges is often the most difficult and costly portion of a water pollution control system. The solids generated by stormwater treatment systems must be carefully considered when designing control facilities. The assessment includes three principal areas:

1. Characterization of the solids by quantity, concentrations, and mass loading
2. Sludge thickening and dewatering
3. Final disposal of sludges

Characterization

A limited amount of work has been done to investigate the properties of stormwater and combined sewerage treatment sludges. The pollutant concentrations of samples reported by one investigation are shown in Table 49 [36].

TABLE 49. CHARACTERISTICS OF SLUDGE FROM COMBINED SEWER OVERFLOW TREATMENT [35]
mg/L

Location	SS	VSS	BOD	Total phosphorus as P	Total Kjeldahl nitrogen as N
Boston, Massachusetts	110 000	41 400	12 000	293	28
Kenosha, Wisconsin	8 300	5 225	1 700	194	492
Milwaukee, Wisconsin					
Hawley Road	41 900	10 570	3 200	149	517
Humboldt Avenue	17 400	8 425	2 200	109	56
New Providence, New Jersey					
Primary, wet weather	1 215	780	728	22	65
Primary, dry weather	3 840	3 200	1 600	41	214
Secondary, wet weather	25 070	14 770	11 200	436	6
Secondary, dry weather	4 620	3 610	2 950	93	277
Philadelphia, Pennsylvania	7 000	1 755	......	12	46
Racine, Wisconsin	8 433	3 340	1 100	39	112
San Francisco, California	22 500	8 850	1 000	166	375

The samples represent several different types of stormwater treatment sludges and, although there are not enough samples to indicate definite relationships, some observations about solids concentrations can be made. Two samples were taken from sedimentation basins in Milwaukee (Humboldt Avenue) and Boston (Cottage Farm). The suspended solids concentrations ranged from 1.74 to 11% with a volatile percentage of 38 to 48%. The large variation in concentrations is probably due to basin design and settling time as well as physical differences in combined sewer overflow characteristics. The samples from Philadelphia and Racine are screen backwashings and backwashings with some flotation scum, respectively. They show lower solids concentrations than the sedimentation sludges and the volatile portion is only 25 to 40%. The San Francisco and Milwaukee Hawley Road samples have been taken from the float portion of dissolved air flotation tanks. They show a solids concentration from 2.25 to 4.19%. The final two sets of samples came from biological processes at Kenosha and New Providence. The wet-weather samples had a solids concentration range of 0.12 to 2.5% but a high volatile fraction.

Although different designs for the stormwater control facilities would affect the solids concentrations, it appears that sedimentation produces the most concentrated sludge with flotation, biological process, and screening sludges becoming more dilute in that order.

Sludge Thickening and Dewatering

The treatability of stormwater solids was also studied by Envirex [3]. Cost-effective sludge handling and disposal requires that the solids be easily thickened for digestion or dewatered for incineration or land disposal. The results of the laboratory scale concentration tests are given in Tables 50 and 51 and summarized in Table 52. The results show that most of the sludges can be concentrated by conventional techniques.

TABLE 50. THICKENING OF SLUDGE FROM COMBINED SEWER OVERFLOW TREATMENT [35]

	Gravity thickening					Flotation thickening				
	Raw sludge sample, % solids	Thickened sludge, % solids	Mass loading, lb/ft² d	Chemical used	Chemical dose, lb/1000 lb	Thickened sludge, % solids	Mass loading, lb/ft² d	Recycle, %	Chemical used	Chemical dose, lb/1000 lb
Boston, Massachusetts - sludge from combined sewer overflow storage basin	11 0 4 4	14 . ..	32	.. . .	. ...	7.2	40	... 570	. 105C[a]	. 0 56
Kenosha, Wisconsin - contact stabilization reaction tank	0.83	1 0	5	C-31[b]	12	3.1	20	190	C-31[b]	5 35
Milwaukee, Wisconsin										
Hawley Road - flotation sludge	3.65	10	34	. .	..	13	60	380	3A3[c]	1 05
Humboldt Avenue - chemically clarified Sludge from storage basin	1 74	6	9	.	...	14	22	750	......	.
New Providence, New Jersey -										
Primary clarifier, wet weather	0 12	8.0	80	837-A[d] CaO	5 333	5 9	80	160	. . .	...
Primary clarifier, dry weather	0 38	5 0	4	. ...	.	4 0	10	230	. ...	
Final clarifier, wet weather	2 5	4 0	4	$FeCl_3$ 905-N[e]	105 2	4.1	30	290	837-A[d]	0 29
Final clarifier, dry weather	0 46	2 0	5	. ... .		8 0	20	290	......	.
Racine, Wisconsin - screen bachwash and flotation sludge	0 84 2 72 6.9	10 .	<400	. .	..	8 19	10 80	380 185	... .	. ..
San Francisco, California - flotation sludge	2 25	4 5	2	....	...	6 1	20	365	105C[a]	0 26

a. Altasep 105C cationic polyelectrolyte.

b. Dow C31 cationic polyelectrolyto.

c. Altasep 3A3 anionic polyelectrolyte

d. Magnafloc 837-A anionic polyelectrolyte.

e. Magnafloc 905-N nonionic polyelectrolyte.

TABLE 51. DEWATERING OF SLUDGE FROM COMBINED SEWER OVERFLOW TREATMENT [35]

Source of sample	Raw sample, % solids	Centrifuge: Dewatered sludge, % solids	Centrifuge: Solids recovery, %	Centrifuge: Chemical used	Centrifuge: Chemical dose, lb/1000 lb	Vacuum filtration: Cake solids, %	Vacuum filtration: Yield, lb/ft²·h	Vacuum filtration: Filtrate solids, %	Vacuum filtration: Chemical used	Vacuum filtration: Chemical dose, lb/1000 lb
Boston, Massachusetts - sludge from combined sewer overflow storage basin	11.0	34	92	105C[a]	0 18	..	..	.....	.....	. ....
Kenosha, Wisconsin - contact stabilization reaction tank	0 84 2.59 3.10	9 7	0 0 ..	....	....	 15	 4	 82	..... FeCl3 CaO	... .. 60 128
Milwaukee, Wisconsin										
Hawley Road - flotation sludge	3.7 9.9	23 30	92 95	...... 3A3[b]	. .... 0.20	. 36	 7	 232	3A3[b] CaO	0.76 95
Humboldt Avenue - chemically clarified sludge from storage basin	1.74	32	95	C-41[c]	3.4	..	..	.....	... .	......
New Providence, New Jersey -										
Primary clarifier, wet weather	0 12 2.5	1.5	77 ..	....	... .	.. 28	.. 4	 82	FeCl3 CaO	54 160
Primary clarifier, dry weather	1.75 2.6	13	92 ..	....	....	. 22	.. 7	 68	FeCl3 CaO	206 38
Final clarifier, wet weather	2 5 3.15	8	92 ..	FeCl3 905N[d]	1 458	.. 19	.. 4	 231	FeCl3 CaO	85 254
Final clarifier, dry weather	0.46 2.6	2.6	90 ..	FeCl3	216	.. 14	.. 2	 45	FeCl3 CaO	567 212
Racine, Wisconsin - screen backwash and flotation sludge	7.5 2.7	33	96 ..	....	....	.. 23	.. 3	..... 1 400	1A1[e] CaO	0 74 147
San Francisco, California - flotation sludge	2.25	11	93	105C[a]	0.53	18	2	123	CaO	444

a. Altasep 105C cationic polyelectrolyte

b. Altasep 3A3 anionic polyelectrolyte

c. Dow C41 cationic polyelectrolyte

d. Magnafloc 905-N nonionic polyelectrolyte

e. Altasep 1A1 anionic polyelectrolyte

$lb/ft^2 \cdot h \times 4.88 = kg/m^2 \cdot d$
lb/1000 lb = kg/1000 kg

TABLE 52. SUMMARY OF CONCENTRATION OF COMBINED SEWER OVERFLOW TREATMENT SYSTEMS

Location	Treatment	Sludge volume/ volume of raw combined sewer overflow, %	Solids content of sludge, %	Sludge concentration (pilot studies) - solids content of sludge, %			
				Gravity	Flotation	Centrifuge	Vacuum filter
Boston, Massachusetts	Storage	0.2	4.4-11.0	14	6-8	30-35	. .
Kenosha, Wisconsin	Activated sludge	3.5	0.83	1	3	9	15
Milwaukee, Wisconsin							
Hawley Road	Flotation	0.4	3.65	10	13	23-30	36
Humboldt Avenue	Storage	0.9	1.74	6	11-14	30-35	....
New Providence, New Jersey	Trickling filters	0.7					
Primary, wet weather			0.12	8	6	1.5	28
Primary, dry weather			0.38	5	4	13	22
Secondary, wet weather			2.50	4	4	7.5	18.5
Secondary, dry weather			0.46	2	8	2.6	14
Philadelphia, Pennsylvania	Microscreens	6.0	0.2	..	.....	.....	....
Racine, Wisconsin	Screens/ flotation	4.8	0.84	10	13	20-33	23
San Francisco, California	Flotation	0.4-0.7	2.25	4	6	11	18

Final Disposal of Sludge

There are two basic options for the disposal of sludge from stormwater treatment facilities:

1. Bleedback of solids to the dry-weather treatment plant using either the extra capacity of existing sludge disposal units or adding capacity to handle storm related loading.

2. Handling of the sludge at the site of stormwater treatment facility with a treatment system dedicated solely to stormwater solids.

Bleedback to the Dry-Weather Treatment Plant--

It is a common practice to transport stormwater solids to the sewage treatment plant after the storm event has subsided. This can be done either for the total flow from a holding basin or sludges from treatment facilities. The simplest transport method is to feed the solids into the sanitary sewer system or interceptor at a controlled rate. The two principal design considerations of a bleedback system are the capacity of the delivery system and the ability of the treatment plant to handle the additional mass loading. The effect on treatment plant capacity is illustrated in Example Problem 5-1.

The mechanics of sludge transport have been studied for conventional sewage treatment plants and can be applied to stormwater sludge. The solids concentration and flow velocity are the two most important parameters to consider. Sludge concentrations greater than 6% become difficult and expensive to pump. At low velocities, the solids will tend to settle out in the sewers (potentially restricting or clogging the lines) and may be resuspended during high flow periods causing slug loading at the treatment plant. The basic flow mechanics principles can be used to investigate existing sewer lines to determine if bleedback into the sanitary sewer system is feasible or if a dedicated sludge main is required.

In addition to potential overloading of a dry-weather treatment plant with storm flows, it is possible that toxic elements in runoff could disrupt biological processes such as secondary treatment and sludge digestion. Storm runoff may contain greater concentrations of certain toxic substances than commonly found in domestic sewage, and the addition of runoff or stormwater treatment sludge to a wastewater treatment plant may be toxic to the biological treatment organisms. It is difficult to pinpoint the levels of metal concentrations that will decrease biological activity. Metals can have complex synergistic effects; biological organisms vary in their susceptibility; and biomasses may become acclimated to low metal concentrations. Several investigators have studied metal toxicity in biological sewage treatment systems and the results are shown in Table 53. The concentrations shown are the levels at which reduced efficiency was noted in the treatment system indicated.

The expected concentrations of metals in sludges from combined sewage treatment facilities was tabulated in reference [36] and is reproduced as Table 54. Comparison of Tables 53 and 54 indicates that the raw sludge may be

EXAMPLE PROBLEM 5-1. IMPACT OF STORMWATER TREATMENT SOLIDS ON THE DRY-WEATHER TREATMENT PLANT

Determine the bleedback loading to a dry-weather plant from a satellite stormwater treatment facility for a 1 in. rainstorm and compare the loading to average plant loads.

Specified Conditions

1. Tributary area population = 50 000
2. Average dry-weather flow = 150 gal/capita·d
3. Average suspended solids concentration = 200 mg/L
4. Combined sewer area = 5 000 acres

Assumptions

1. Fifty percent of the rainfall over the area will run off and overflow to the stormwater treatment facility.
2. The average suspended solids concentration of the overflow = 300 mg/L.
3. The stormwater treatment facility will capture 50% of the overflow solids.
4. The captured solids will be pumped to the dry-weather treatment facility headworks at a solids concentration of 2%.
5. The dry-weather plant will operate satisfactorily at an overloading of 125% of average flow.

Solution

1. Compute average dry-weather flow and solids loading

Flow = 50 000 people x 150 gal/capita·d
= 7.5 Mgal/d
SS = 7.5 Mgal/D x 200 mg/L x 8.34 lb/gal
= 12 500 lb/d

2. Compute volume of stormwater treated at the satellite stormwater treatment facility.

Volume = 1.0 in. rain x 0.5 x 5 000 acres x 0.027 Mgal/acre in.
= 66.7 Mgal

3. Compute mass and volume of stormwater treatment sludge pumped to the dry-weather plant.

Mass = 66.7 Mgal x 300 mg/L x 8.34 gal x 0.50 capture
= 83 000 lb
Volume = 83 000 lb 0.02 solids concentration 8.34
= 0.50 Mgal

4. Comparison

	Flow	Solids
Average-dry weather conditions	7.5 Mgal/d	12 500 lb/d
Overflow from a 1 in. storm	0.50 Mgal	83 000 lb

Comment

The problem shows that the runoff from a basin can be reduced to a manageable flow quantity with satellite stormwater treatment but the solids will present a serious problem for bleedback. The dry-weather plant could handle the flow in its 25% buffer capacity over a period of 7 hours, however, the solids would need more than 25 days of bleedback to be treated in the spare capacity. Obviously, the 1 in. storm is far too large to be treated and bledback to an existing dry-weather facility. Expanded treatment units or large storage basins would have to be available.

potentially toxic to aerobic treatment systems but not to anaerobic digestion. The potential toxicity must be examined for each installation to determine the actual concentration of metals in the treatment plant effluent. In most cases, the sludge would be combined with sanitary sewage that had low metal concentrations. The resulting diluted influent would not be toxic to the treatment organisms. However, bleedback operations will usually take place during periods of low sanitary sewage flow, when the available hydraulic capacity of the treatment plant is the largest, but dilution capacity is low.

TABLE 53. CONCENTRATIONS OF METALS REPORTED TO CAUSE REDUCED EFFICIENCY IN BIOLOGICAL TREATMENT SYSTEMS
mg/L

Reference No.	Silver	Nickel	Copper	Chromium	Zinc
Aerobic systems, raw sewage					
[37]	10	10	25	25	100
[38]	..	1-2 5	1	10	5-10
[39]	..	2-2 5	1	1	2-5
Anaerobic digestion, sludge					
[38] (primary)	..	62	280	330	375
[38] (waste activated)	..	89	160	530	328
[40]	..	500	14-150	500	100-1 000

TABLE 54. METAL CONCENTRATIONS IN VARIOUS COMBINED SEWAGE OVERFLOW TREATMENT SLUDGES [36]
mg/L

Treatment process	Nickel	Copper	Chromium	Zinc	Lead	Mercury
Storage alone	0.1	1.5	0.05	0.6	0.7	0.001
Storage/sedimentation	2.5	8.4	4.4	15.2	29.0	0 05
Dissolved air flotation	2 3	10 0	45.6	19.4	43.3	0 11
Screening/dissolved air flotation	1.8	4.1	1.8	13.8	8.6	0.02
Microscreening	2.0	1.4	0.4	8.3	17.1	0.01
Contact stabilization	5.3	14.5	17.3	71.5	5.3	0.03
Trickling filter	25.2	32.8	79.5	41.7	11.4	.....

Bleedback of stormwater treatment sludges to a sewage treatment plant has the advantage of locating all of a district's sludge disposal operations at one site with maximum utilization of reserve capacities. However, stormwater sludges cannot be neglected and the loadings must be considered in the design of or additions to the treatment plant.

Handling of the Sludge at the Site of the Stormwater Treatment Facility--

If it is necessary to maintain sludge handling facilities at stormwater treatment sites, the characteristics of the sludges should be carefully considered in facility design. Basically, the sludge will have to be dewatered and disposed of by a treatment system similar to ones used for municipal sewage sludge. The intermittent nature of storm events, and consequently stormwater sludge, will probably rule out some common processes for remote facilities that treat only stormwater sludges. Biological systems, such as digestion, that require a continuously fed biomass and other systems, such as incineration, that would require extended startup times would not be used at stormwater treatment sites. Thickening, vacuum filtration, pressure filtration, and centrifugation would all be acceptable means of volume reduction and the best options for disposal are either land filling or land spreading, preceded by a heat or chemical stabilization step to decrease nuisance and health hazard potential. There is little existing design experience to indicate that any of these common dewatering or disposal techniques are particularly suited to stormwater solids treatment.

RECEIVING WATER IMPACTS

The goal of a stormwater runoff study is to evaluate the impact of runoff and combined sewer overflows on the receiving waters and decide what control alternatives would be most cost effective in reducing wet weather pollution. An evaluation of the way in which receiving water characteristics are influenced by stormwater runoff is always difficult to perform because of the masking effect of municipal and industrial point sources, because runoff events are both intermittent and highly variable, and because of carryover effects of stormwater benthic deposits. The impact of a storm varies with rainfall volume, duration, intensity, and the antecedent conditions of the basin.

The methodology frequently used to study the impact of stormwater on streams, lakes, and estuaries is to model the characteristics of runoff for a variety of storm conditions and input the resulting mass loadings into a receiving water model. A modeling approach allows the investigator to study a large variety of storm and stream conditions that probably would not occur during the time frame of the project. Modeling also allows the study of one of the many variable influences while keeping the remaining ones constant. The methodology for modeling stormwater pollutants has been presented in earlier sections of this report. Other methods include direct measurement and simple correlations.

Obviously, impacts are often very site specific and the extent of the problems will depend heavily on local conditions, such as rainfall quantities, point sources of pollution and their treatment, land use, and the sensitivity of the receiving water. Urban stormwater pollution can be manifested in a number of ways depending on the specific factors of the locality being studied. Individual site conditions will influence both the mass loading of pollutants and the ability of the receiving water to assimilate the loading. Problems result when loadings exceed the assimilative capacity of a stream or lake and the use of the water is impaired. The classes of problems that may be caused can be broadly categorized as follows [41]:

- Aesthetic deterioration and solids - Either general appearance (dirty, turbid, cloudy) or the actual presence of specific, objectionable conditions (odors, floating debris, oil films, scum or slimes, etc.) may make the receiving water unattractive or repugnant to those in its proximity. In addition, particulate matter may cause the formation of sediment deposits that smother bottom dwelling aquatic organisms or restrict river flows contributing to flooding potential. Excessive solids can also make the receiving water an unacceptable source for agricultural irrigation water.

- Dissolved oxygen depletion - Organic materials stimulate the growth of bacteria which may consume oxygen faster than natural processes can replenish. This condition may or may not be visually apparent. In the extreme, discoloration, gas formation, and odors may be apparent--however, well before this extreme is reached, conditions suitable for a balanced aquatic population of fish and lower species in the food chain may be violated. The presence of unoxidized nitrogen compounds (e.g., ammonia) is in some cases a significant element in water quality problems related to low dissolved oxygen levels.

- Pathogen Concentrations - The presence of excessive concentrations of objectionable microorganisms can impair the ability to utilize the receiving water for certain water supply and recreational purposes.

- Nutrients - The discharge of materials which fertilize or stimulate excessive or undesirable forms of aquatic growth can create significant problems in some receiving water systems. Overstimulation of aquatic weeds or algae (eutrophication) can be aesthetically objectionable, cause dissolved oxygen problems, and in extreme cases, can interfere with recreational use and create odors and heavy mats of floating material at shorelines.

- Toxicity - Toxicity problems can fall into either of two categories: (1) metals/pesticides/persistent organics, which may exhibit a subtle, long-term effect on the environment in areas well removed from the area under consideration by the discharge of small quantities which gradually accumulate in sensitive areas, and (2) ammonia and byproducts of effluent chlorination which, under some conditions, can exhibit a local, more immediate impact.

Dissolved Oxygen Depletion

The classical problem related to organic pollution of receiving waters is the consumption of instream oxygen by the bacterial breakdown of organic material. The resulting low levels of oxygen will destroy sensitive species of fish and aquatic organisms. The organic material (and unoxidized nitrogen compounds) in runoff can be important to the oxygen balance of streams.

Colston studied the dissolved oxygen (DO) sag for a watershed in North Carolina by analyzing several storm types and intervals during storms. The results of the study are presented in Table 55.

TABLE 55. RESULTS OF OXYGEN SAG COMPUTATIONS FOR DURHAM, NORTH CAROLINA [12]

Storm type	Rainfall, in.	Storm component	Storm flow, ft^3/s	BOD_{20}, mg/L	DO at sag point, mg/L
Small	0.1	Total	40	40	10.0
Small	0.1	Total	20	31	10 0
1 to 2 yr storm	1.0	First flush	200	75	4 5
		Peak	315	62	3.8
		Falling limb	200	47	6.5
		Tail	75	37	8.7
5 yr storm	3.3	First flush	500	85	0
		Peak	1 100	70	0
		Falling limb	800	54	0.3
		Tail	300	42	5.9
7 d, 10 yr low flow	...	....	0.3	15	0

in. x 2.54 = cm
ft^3/s x 28 316 = L/s

The analysis shows that the severity of DO depletion increases with the size of the storm and is most severe for the slug of runoff at the peak of the storm. The study was performed for the Third Fork Creek and the river characteristics and reaeration coefficients are necessarily site specific.

In a study for the Corps of Engineers the impact of urban runoff from basins in the Atlanta, Georgia, area was analyzed [10]. The effects of a 1.02 cm (0.4 in.) storm on a highly urbanized basin were plotted to determine the impact on dissolved oxygen levels in the Chattahoochee River. The DO profile in Figure 20 shows that the DO decreased to a level of 1.5 mg/L approximately 48.3 km (30 mi) downstream from the addition of runoff. The level is below the state standard of 5 mg/L of dissolved oxygen. Estimates from the study indicate that this urban basin alone will cause a violation of stream standards during 50% of the rainfall events.

Pathogen Concentrations

Excess concentrations of bacterial indicator organisms in urban runoff will prevent water supply and recreational use of the receiving water. Although stormwater runoff should not contain fecal contamination, several investigators have measured significant levels of contamination. The sources are probably faulty septic tanks, illegal cross-connections, and contamination by domestic animals. The results of some investigations are shown in Table 56 [2, 42, 43].

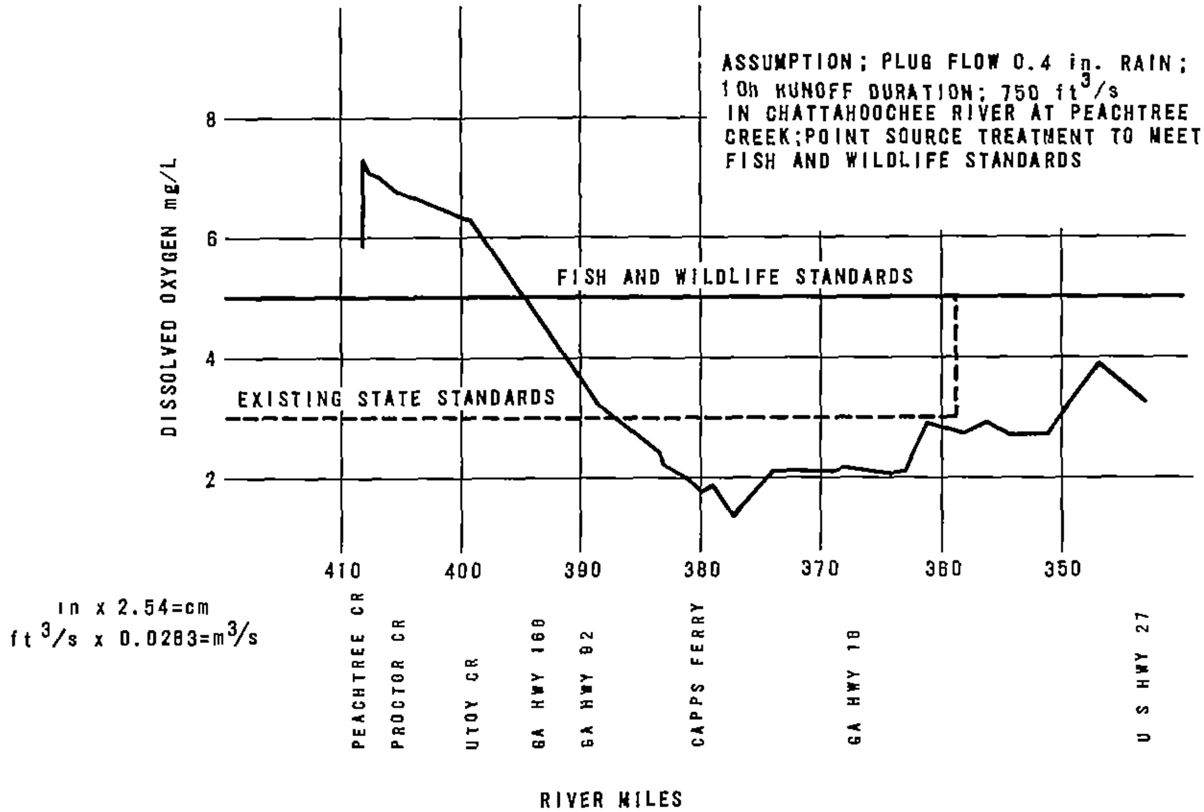

Figure 20. Impact of urban runoff on the Chattahoochee River [10].

TABLE 56. REPORTED BACTERIAL CONTAMINATION OF STORMWATER POLLUTANTS
Organisms/100 mL

	Total coliforms	Fecal coliforms	Fecal streptococci
Business district [42]	......	13 000	51 000
Residential [42]	......	6 500	150 000
Rural [42]	......	2 700	58 000
Cincinnati, residential [2]	58 000	10 900	20 500
Miami [43]			
Residential	5 100	3 600	700
Parking lot	50 500	49 800	1 200
Residential	19 400	16 400	1 100

A common bacterial standard for recreational use of water is a total coliform count of less than 1 000 organisms per 100 millilitres and a fecal coliform level of less than 200 organisms per 100 millilitres. Looking at Table 56, it is clear that stormwater runoff will contaminate the receiving water at an outfall and, depending on diffusion and dilution, may make adjacent areas unacceptable for water contact recreation.

Nutrients

The influx of nutrient materials into a body of water will fertilize and stimulate the aquatic weeds and algae. The function of urban runoff in supplying the excess nutrients to receiving waters has to be examined in an effort to curtail lake eutrophication.

The Lake Wingra watershed in Madison, Wisconsin, was investigated to compute the source of nutrient loading. A tabulation of nutrient sources is given in Table 57.

TABLE 57. NUTRIENT SOURCES FOR LAKE WINGRA [44]
lb/yr

Source	NH_3-N	NO_3-N	Org-N	Soluble P	Total P
Precipitation	860	880	570	55	70
Dry fallout	1 230	1 060	2 420	46	240
Flow from springs	370	9 120	...	66	170
Urban runoff	990	1 320	7 710	1 120	2 160

lb/yr x 0.0703 = kg/yr

The urban runoff is an important part of the mass balance especially for the phosphorus loading. More than 80% of the influent phosphorus comes from runoff.

An analysis of potential phosphorus loadings on Atlanta area reservoirs was made to evaluate the eutrophic potential. The Atlanta data are summarized in Table 58. The estimated loadings of phosphorus from only urban runoff were compared to permissible loading rates developed by Vollenweidor in a worldwide study of eutrophic lakes [10].

Several of the reservoirs will be exceeding the permissible phosphorus limits and, depending upon nitrogen and light availability, will be expected to experience some degree of eutrophication.

Toxicity

Urban runoff can be an important source of the metals and pesticides that can be toxic to aquatic life. It is very difficult to isolate the instream impacts of toxic elements from urban runoff and very little work has been attempted. One study did quantify the amount of potential toxins on street surfaces to help analyze the potential for adverse impact. A summary of this ten city study that analyzed the components of street solids is shown in Table 59.

TABLE 58. URBAN RUNOFF PHOSPHORUS LOADINGS COMPARED TO THE POTENTIAL FOR LAKE EUTROPHICATION [10] $lb/1000\ ft^3$

Reservoir	Projected phosphorus loadings		Vollenweider's loadings	
	1980	2000	Permissible	Dangerous
Morgan Falls	0 246	0.448	0.18	0.34
Jackson Lake	0.185	0.257	0.05	0.10
Stone Mountain	0.046	0.063	0.04	0.07
Lake Allatoona	0.011	0.180	0.03	0.06
Lake Spivey	0.002	0.004	0.05	0.09
Clayton County Water intake	0.025	0.045	0.02	0.04

$lb/1\ 000\ ft^3 \times 0.0160 = kg/m^3$

TABLE 59. POTENTIALLY TOXIC ELEMENTS IN STREET SURFACE SOLIDS [1]

Element	Loading, lb/curb mi
Chromium	0.11
Copper	0.20
Zinc	0.65
Nickel	0.05
Mercury	0 73
Lead	0.57
Cadmium	0.003
Total heavy metals	1.6
Total pesticides	$1\ 420 \times 10^{-6}$
PCB	$1\ 100 \times 10^{-6}$

lb/curb mi x 0.2819 = kg/curb km

Although the street surface loadings are not a precise measurement of the quantities that can wash off in a storm event, it is an indication of the reservoir of toxins available.

In his study in North Carolina, Colston measured the concentrations of metals in stormwater runoff samples. The ranges of values detected for some of the metals are presented in Table 60.

TABLE 60. CONCENTRATIONS OF METALS IN URBAN RUNOFF FROM DURHAM, NORTH CAROLINA [12]
mg/L

		Range	
Pollutant	Mean	High	Low
Chromium	0.23	0.47	0 06
Copper	0.15	0.50	0 04
Lead	0.46	2 86	0.1
Nickel	0.15	0 29	0 09
Zinc	0 36	4 6	0 09

Relative Quantities of Urban Stormwater Pollutants

The signficance and relative importance of urban runoff as a source of pollution can be demonstrated from the work of Colston in Durham, North Carolina [12]. His study resulted in the comparison shown in Table 61.

TABLE 61. COMPARISON OF RAW MUNICIPAL WASTE AND URBAN RUNOFF [12]
lb/acre·yr

Pollutant	Raw municipal wastes	Urban runoff
COD	1 027	938
BOD_4	685	470
Suspended solids	335	6 690
Kjeldahl nitrogen as N	. ..	6 1
Nitrate as N	7.2	....
Total phosphorus as P	11	4 7
Chromium	0 10	1 6
Copper	0.20	1 6
Lead	0.08	2.9
Nickel	0 16	1.2
Zinc	1 5	2.0

lb/acre·yr x 1.21 = kg/ha·yr

The results indicate that even with an acceptable level of treatment for the municipal waste, the water quality of the receiving stream would be degraded by urban runoff. During periods of wet weather, the stream quality is controlled by the urban runoff characteristics, not municipal sewage loadings.

Instream characterization of the chemical quality of the Roanoke River during both wet- and dry-weather periods also indicates the importance of runoff on water quality. The results are tabulated in Table 62.

TABLE 62. POLLUTANT CONCENTRATIONS IN ROANOKE RIVER TRIBUTARIES DURING WET- AND DRY-WEATHER CONDITIONS [45]
mg/L

Pollutant	Murray Run	Trout Run	24th Street
BOD			
Dry weather	8	3	8
Wet weather	17	18	20
Total solids			
Dry weather	248	281	194
Wet weather	623	460	514
Total volatile solids			
Dry weather	85	147	126
Wet weather	134	139	172
Suspended solids			
Dry weather	37	17	20
Wet weather	89	93	103
Volatile suspended solids			
Dry weather	12	8	7
Wet weather	25	28	24

As shown, the solids and organic levels increase at least two-fold for periods of runoff.

A third study in Metropolitan Seattle also surveyed two urban creeks to compare quality constituents for dry- and wet-weather periods [46]. Harper found the following increases in concentration during the wet season: BOD, 4 mg/L; PO_4, 0.5 to 1 mg/L; total solids, 20 to 30 mg/L; and turbidity, 10 to 30 FTU. Zinc levels increased significantly in both streams while lead and copper increases were significant in one of the streams. Although the BOD levels were higher during the wet season, the dissolved oxygen concentrations in the streams did not decrease. The authors credit this fact to an increased rate of stream reaeration during storm periods due to higher stream velocities and increased turbulence. The BOD-dissolved oxygen relation shows the importance of the nature of the receiving water in evaluating pollutant impacts. A more placid stream or river may have exhibited a DO sag due to the BOD loading and less reaeration. The ultimate receiving water should also be considered in a regional analysis; in this case, the urban runoff may have caused some DO depletion near the stream mouths in Puget Sound.

In addition to the chemical constitutents of the Seattle creeks, the benthic communities were studied and compared to a clean water creek. The results indicate a lower quantity of sensitive organisms and a poorer diversity index in the urban streams. The inhibited nature of the benthic community is attributed to a combination of sedimentation, scouring, and chemical toxicity from metals, oil, and grease.

The high variations in flow in urban streams may be the most important deterrent to the development of a stable community. The increasing imperviousness of the developing area causes an increase in runoff volume and a faster stream reaction to precipitation. The base flow of a stream decreases and storm peaks increase. The stream fauna cannot adapt to highly variable flows, scour, and increased sediment.

SECTION 6

BEST MANAGEMENT PRACTICES FOR STORMWATER POLLUTION CONTROL

Much emphasis is currently being placed on controlling stormwater pollution by attacking the problem at its source, as opposed to potentially more costly downstream treatment facilities. These source controls, termed "Best Management Practices" (BMP), are a practice or combination of practices that are determined to be capable of being implemented and most effective in reducing the amount of pollution generated by a nonpoint source to a level compatible with water quality goals.

Best Management Practices are classified into two groups: (1) planning, where efforts are directed to the control of future development or redevelopment of existing areas, and (2) maintenance and operational practices to reduce the impact of nonpoint source contamination from existing developed areas.

Successful stormwater pollution control depends on the effective implementation of the proposed planning efforts and/or control practices. Legislation or ordinances, to force or encourage conformance with the intended BMP, has been found most effective in achieving this end. Essential to successful implementaion and enforcement is a concerted effort to monitor compliance with the intended legislation and educate not only those who will bear the responsibility of regulation, but the public as well.

PLANNING

The concept of preventing and reducing the source of stormwater pollution best applies to developing urban areas, for these are areas where man's encroachment is yet minimal, or at least controllable, and drainage essentially conforms to natural patterns and levels. Such lands, in consequence, offer the greatest flexibility of approach in preventing pollution. What is required, therefore, is to manage development in such a way that a runoff regime may be retained close to natural levels. It is in these new areas where proper management can prevent long-term problems.

The goal of planning is to develop a macroscopic management concept to prevent the problems resulting from short-sighted development of individual areas. When considering stormwater management, the planner is interested in controlling the volume and rate of runoff as well as the pollutional characteristics. The goal is to preserve the initial ecological balance so that expensive downstream treatment facilities can be minimized. Since the size of storm sewer networks and treatment plants is quite sensitive to the flow, quantity, and particularly the peak flowrate, a reduction in total volume or a smoothing out of the peaks will result in lower construction costs.

Land Use Planning

The starting point of land use planning is the knowledge that traditional urbanization upsets the natural hydrologic and ecologic balance of a watershed. The degree of upset, and whether it is beneficial or detrimental, depends on the mix, location, and distribution of the proposed land use activities. As man urbanizes an area, the receiving waters are degraded by runoff from his activities. Effective planning requires that limits be put on the stream degradation and that the quantitative effects of development options be evaluated to weigh their merits and decide what restrictions should be placed on the residuals emitted from each site.

Computer simulation is an important planning tool for examining the interacting pollutant sources in a watershed. By modeling the runoff process for urbanizing areas, a planner can predict the effects of proposed plans and the ability of controls to solve potential problems. The receiving water system and point sources of pollution should be included in the evaluation to understand the relative importance of urban runoff. Several existing models that can be used to examine the runoff process have been described in Section 4. Water quality criteria standards can be recommended after investigating the sources of pollution and the ability of the receiving water to absorb loadings.

Having set goals for the watershed, the planning agency has two basic choices for achieving the water quality standards. Either the individual sites can be forced to comply with individual practices and performance standards that fit into the master plan, or the basin system can be designed and maintained as a public utility. The decision on how to blend the options to meet specific site conditions is the key to implementing a basin plan. Isolated development tracts can be controlled by requiring developers to follow specific source control practices, or a simple set of performance standards can be applied and the choice of practices can be left up to the developer. For example, the agency can require that the runoff from the developed site must not exceed predevelopment intensity. The developer will have to minimize runoff producing areas and provide detention facilities at the site.

When dealing with individual or small-scale construction in an urbanizing area, a public utility must ensure that stormwater control planning is implemented. The utility needs the power to acquire land to preserve natural floodways and infiltration areas before development overruns the best sites. Dealing with the small-scale development is a difficult political problem when stressing nonstructural controls. Plans must be developed, and specific sites must be set aside for greenways, detention ponds, and floodways before urbanization begins. This involves buying the land or inverse condemnation before the tax base has been developed to pay for it.

Planners also must consider the effects of their actions on areas outside the individual watershed. For example, detaining storm flow in a downstream watershed while it remains unregulated upstream can cause higher flood levels in the river than a completely unregulated system.

Use of Natural Drainage Features

The traditional urbanization process upsets the existing water balance of a site by replacing natural infiltration areas with roadways, parking lots, roofs and other impervious areas. The increased quantity of runoff is carried away in concrete culverts or compacted earth channels instead of in natural channels and grassy floodways. The net impact is increased runoff, decreased infiltration to the groundwater, and increased flowrates. The increased flow velocities will mean increased channel erosion and the transport of surface material to receiving waters. Although most of the surface material is natural and harmless on the land, it will become a water pollutant contributing to stream degradation. If the natural drainage features can be preserved, flowrate increases will be minimized and pollution loads contained.

The key to preserving a natural drainage system for an urbanizing area is understanding the predevelopment water balance and designing to minimize interference with the system. The soils and hydrology of the site must be studied so that high-density, highly impervious construction, such as shopping centers and industrial complexes, is located in areas with naturally low infiltration potential, and the best recharge areas are preserved as open, undisturbed space in parks and woodlands. Runoff from developed areas should be directed to the recharge areas and detained to make the best use of the full infiltration potential. Any necessary drainage channels should be modeled on the natural swales of the undeveloped site. The broad, grassy swales will slow down the runoff and maximize infiltration. The drainage plan can include variable depth detention ponds that will rise during a runoff event and return to a base level during dry weather.

Realizing that the goal of the design is maximizing infiltration-recharge and minimizing runoff, the planner should be able to incorporate the following techniques into the site plan:

- Roof leaders should discharge to pervious areas or seepage pits.
- As much area as possible should be left in a natural undisturbed state. Earthwork and construction traffic compact the soil and decrease infiltration.
- Steep slopes should be avoided. They will contribute to erosion and lessen recharge.
- Large expanses of impervious area should be avoided. Parking lots can be built in smaller units and drained to pervious areas.
- No development should be permitted in flood plains.

An interesting technological answer to the problem of preserving pervious area is the possibility of using an open graded asphaltic concrete as a paving material. Experiments have shown that it will serve as a porous pavement, allowing as much as 64 cm/h (25 in./h) of stormwater to infiltrate through the pavement [1].

Preliminary investigations have shown promise that it can withstand stability, durability, and freeze-thaw tests, and that it is comparable in cost to conventional paving with drainage. Long-term tests will have to be made of its resistance to clogging and the effects on the quality of water that filters through the pavement. If the soil under the pavement and base is free draining, the rainwater will infiltrate quickly into the ground; however, porous pavement can also serve as a ponding device if storm quantities exceed soil capacity. The porous nature of the pavement permits water to be stored in the pavement. A pavement with a 10 cm (4 in.) surface course and 15 cm (6 in.) base course could store 6.1 cm (2.4 in.) of runoff in its voids. The proven use of porous pavement can be an important tool in preserving natural drainage.

If natural drainage techniques are developed at a site, the resulting system should provide a water balance closely approximating the predevelopment conditions. The site will be less densely populated than most planned areas; however, the planner will have a community that should be more desirable to live in. In addition, it has been estimated that a natural drainage system costs about $1500 less per hectare ($600 less per acre) than a conventional system [2].

Erosion Controls

The control of erosion from construction and developing sites will have a major impact on the total pollution loads imposed on receiving waters. Current estimates indicate that approximately 3900 km^2 (1500 mi^2) of the United States is urbanized annually. All of this land is exposed to accelerated erosion.

From a knowledge of erosion and the guidelines that have been written concerning erosion control, several basic principles for control of erosion are apparent:

- Reduce the area and duration of soil exposure.
- Protect the soil with mulch and vegetative cover.
- Reduce the rate and volume of runoff by increasing infiltration rates and surface storage and by planned diversion of excess runoff.
- Diminish runoff velocity with planned engineering works.
- Protect and modify drainage ways to withstand concentrated runoff resulting from paved areas.